NsG-219

A RADAR INVESTIGATION OF METEORS OF SUB-VISUAL MAGNITUDES

by

Colin S. L. Keay

(Accepted for publication in the "Astronomical Journal", U.S.A.)

Physics Department,
University of Canterbury,
CHRISTCHURCH 1, NEW ZEALAND.

June, 1964.

ABSTRACT

33919

The operation of an improved type of radar system for delineating meteor radiants is described. The system is capable of detecting the trails produced by 10th magnitude meteors (corresponding to electron densities as low as 5×10^{11} m^{-1}). High rates of detection, quite often exceeding 1000 meteors per hour, are readily obtainable. At these rates it is found that some of the recognized showers are completely masked by the dense background of faint meteors while other shower streams appear to degenerate into scattered sporadic centres of activity.

Author

1. INTRODUCTION.

The classic method of delineating meteor shower radiants from radar observations is that due to Clegg (1948a, 1948b), which utilises the directive properties of an antenna array in conjunction with the specular reflection of radio waves by a meteor trail. Meteors emanating from a given radiant are generally detected only when the radiant point on the celestial sphere passes through the plane normal to the axis of the antenna beam. When the recorded echoes are plotted as a function of time and range the characteristic range-time envelopes of the Clegg method are obtained. From their shape and time of occurrence the co-ordinates (right ascension, α, and declination, δ) of the radiant may be deduced. If two antenna arrays are used (Aspinall, Clegg and Hawkins, 1951) the accuracy of the radiant co-ordinates obtained is greatly improved.

When more than 1000 echoes per day have to be plotted the Clegg method becomes too laborious and time-consuming. A modified approach due to Keay (1957) enables the radiant co-ordinates to be determined by plotting the echo rate from two narrow-beam antennas as a function of time. Only those echoes which lie in a range interval straddling the range of maximum echo occurrence need be used. This "partial rate method", as it is called, speeds the data processing and allows higher echo rates to be dealt with.

Both methods lead to ambiguities whenever two or more radiants are simultaneously active. These may be resolved, at the price of increased system complexity, by incorporating a third antenna, the beam of which should be spaced equally in azimuth with the other two. Each radiant then produces a time-displaced sequence of peaks in the partial rate curves and it becomes very much easier to relate the individual peaks to one another, or show their non-relationship, as the case may be. If three range intervals are recorded from each of the three antennas nine partial rate curves are obtained, thus giving a ninefold check on the validity of a radiant.

The importance of this augmented partial rate method lies in its ability to delineate the radiants of minor showers which produce too few large meteors to make the ordinary Clegg method feasible. Or, putting the matter another way, this method is capable of detecting the presence of shower structure in the sporadic meteor background level.

2. THE TRIPLE-BEAM SYSTEM:

A plan of the antenna coverage is shown in Figure 1. Three narrow-beam antennas are used for reception and a wide angle, low elevation transmitting antenna (fan-beam) directs the R.F. energy to the region searched by the three receiving antennas. All were designed for the operating frequency of 69 Mc. The two outer receiving antennas are multiple yagi arrays giving a beam 4.4 degrees wide in azimuth (Ellyett, Keay, Roth and Bennett, 1961) while the center antenna is a rotatable planar array of half wave dipoles giving a beam 22 degrees wide in azimuth (Ellyett and Roth, 1955). For the purposes of this experiment the rotatable array was directed to a fixed azimuth of 90 degrees east of north. The fan-beam transmitting antenna consists of a vertical stack of folded dipoles spaced 0.35 of a wavelength in front of a reflecting screen. The elevation of the fan-beam produced by this antenna was intentionally made a little higher than that of the beams produced by the other antennas in order to shorten the range at which the maximum number of echoes is received. This has the desirable effect of reducing the bias towards detecting radiants passing close to the local zenith (Keay and Ellyett, 1961). The resulting composite elevation response of the fan-beam antenna together with each of the two yagi arrays has a peak of 11 degrees elevation, while that with the fan-beam antenna and the planar array peak at 13.5 degrees elevation.

The transmitter produced 25 microsecond pulses with a peak power of almost 100 kilowatts at a pulse repetition frequency of 150 pulses per second derived from the frequency of the mains supply.

The detection system consists of three identical receivers (one to each receiving antenna) and a video mixing unit which mixes and codes the echoes for display on the screen of a cathode ray tube. Continuous photographic recording is employed at a film rate of 30 cm per hour. The identification of meteor echoes is based on the principle of doubling each genuine echo to distinguish it from random spikes due to noise and various forms of impulse interference. A small square-wave voltage added to the time-base at half the sweep frequency causes recurrent signals (such as genuine meteoric echoes which last for the duration of several sweeps) to be doubled while random signals stay random. This is illustrated in Figure 2 where the echo from Receiver 1 is doubled with a spacing t proportional to the amplitude of the applied square wave. The echoes from Receivers 2 and 3 are spaced more widely by switching the output signals from these receivers through 50 and 100 microsecond delay lines, respectively, on each alternate sweep in such phase as to add to the displacement caused by the square wave. The effect of this is shown in Figure 2. On the alternate sweeps, when displaced signals are displayed, the range markers are suppressed in order that the undisplaced dot of every echo can be used for range determination.

There are numerous occasions when echoes from a given meteor are received by more than one antenna, due to overlapping radiation patterns. Usually, however, one antenna produces a stronger signal than the others and identification is still possible - as may be seen from the example depicted in Figure 2.

From the system parameters it can be shown that the limiting zenithal magnitude of meteors detected via the fan-beam/yagi array antenna combination is 10.9 ± 0.4. These smallest meteors are detected at an elevation of 14 degrees, corresponding to a range of 360 km. This agrees with the measured value of 365 km at which the maximum occurs in the range distribution of observed meteor echoes.

The limiting zenithal magnitude of meteors detected via the fan-beam/planar array antenna combination is 10.0 ± 0.3. These are detected at an elevation of 17 degrees, corresponding to a range of 305 km. This too is in fair agreement with the 280 km range at which the maximum number of echoes is received via this particular antenna combination.

3. THEORY AND CALCULATIONS:

The basic theory underlying the partial-rate method needs no modification when three instead of two narrow-beam antennas are employed. The counting of meteors in more than one range-band has also been described in a paper (Ellyett, Keay, Roth and Bennett, 1961) in which it is referred to as a multiple rate-count method, and an example of its usefulness was given. It is the combination of these methods which is referred to as the augmented partial-rate method.

Briefly, short time-interval counts of meteor echoes, whose ranges lie in a band centred on the range of maximum occurrence, give a partial-rate curve when plotted against time. The times when peaks occur in the partial rate curves from two or more antennas yield the radiant co-ordinates of the meteor activity which gave rise to the peaks. The same is true when meteors in range-bands adjacent to the central range-band are used, although an allowance must be made for the assymmetrical distribution of meteors within the range-band when high accuracy is required.

The way radiant co-ordinates are derived from the observed times of occurrence of peaks in meteor rate may be seen from Figure 3. This Figure represents a horizontal projection of the intersection with the celestial hemisphere of the planes in which meteor trails must lie in order to be detectable at the range concerned. It is the same as saying that meteors from a given radiant are only detectable as the radiant passes through the appropriate "collecting" plane. For the easterly directed antenna the collecting planes for echoes detected near ranges of 300, 400 and 500 km intersect the celestial hemisphere in the lines N1S, N2S and N3S respectively. In reality the lines are narrow strips due to the finite size of the range interval in which echoes are counted (each "range-band" extended 50 km on either side of the nominal range, i.e. the range intervals were 100 Km wide) and to the spread in azimuth of the antenna beam.

As a somewhat ideal example, the radiant 'A' will first produce echoes in the 500 Km range-band of the South of East antenna (at point 'a' in Figure 3), then in its 400 Km range-band at a time which happens to coincide with the meridian passage of the radiant in this particular case (point 'b'). Echoes will next appear in the 500 Km range-band of the East antenna (point 'c') and almost at the same time in the 300 Km range-band of the South of East antenna (point 'd'). And so on. The important point is that the order of appearance of echoes in the range-bands of the three antennas will be quite different for radiant 'B', and is a function of the radiant declination. However, up to quite high values of declination, the order of appearance of echoes in the various range bands associated with a given antenna is always the same. Also, for radiants passing further north than a few degrees of the zenith, the peak echo rate in a given range-band from the East antenna is always mid-way in time between the peak rates in the same range-band from the other two antennas. These characteristics assist the recognition of discrete meteor shower activity whenever it occurs, but if the measured rates are low (less than about 15 per 12 minute interval in each 100 Km range-band) it must be borne in mind that random fluctuations in echo rate may cause small peaks to vanish entirely from some of the rate curves.

For each range-band of the three antennas the time differences between peak echo rate and the time of meridian passage (local transit) of any culminating radiant have been calculated as a function of radiant declination by using the theory already published (Keay, 1957). A suitable computer program was developed in order to enable this considerable task to be performed on an IBM-1620 computer. The nine tables produced by the computer are shown plotted in Figure 4, which is, in effect, a cartesian projection of Figure 3, using declination and hour angle as co-ordinates.

4. PRELIMINARY RESULTS:

The system as a whole was in operation for several months during 1962 and early 1963. In February 1963 the experiment was discontinued in order to commence a meteor survey (using omni-directional antennas) which could not run simultaneously. However, the results from the preliminary period of operation indicate the desirability of further work when the meteor survey is completed.

During the experiment much valuable experience was gained, particularly on the problems of displaying the outputs of three receivers on a single cathode ray tube. Varying noise levels, particularly when man-made interference was present on any one of the receivers, were difficult to compensate for. The preservation of equal signal-to-noise ratios in each of the three outputs was essential in view of the narrow dynamic range of the cathode ray tube spot intensity and the requirement that a single brilliance setting had to be correct for recording all three signals. This, at present, is the weakest link in the whole system.

A very useful check on the performance of the narrow beam antennas and their associated receivers was provided by a pen recorder which continuously monitored the detector current in each receiver. All records exhibited a prominent peak which recurred every day at the sidereal time corresponding to the passage of the

Sagittarius region of the local galaxy through each of the antenna beams.

One of the first occasions when the complete triple-antenna system was operating successfully was during July, 1962. The partial rate curves obtained on July 25 are shown in Figure 5. In each of the nine curves the δ-Aquarid shower has produced a very prominent peak, allowing quite a good value to be obtained for its radiant position, as follows:

Right ascension	$337.8^\circ \pm 0.5^\circ$
Declination	$-13.7^\circ \pm 2.9^\circ$

The peak in the partial rate curve for the 250-350 Km range interval from the North of East antenna was incomplete because of a gap in the record due to a severe burst of man-made interference. Otherwise the peaks were quite clear and there is no doubt as to their identification. None of the other peaks in these partial rate curves are as prominent, except, perhaps, for the activity from the East antenna near 0800 hours. However, there is very little supporting activity from either of the other two antennas and no radiant can be determined for it. This situation has proved to be surprisingly common in this work, lending support to other evidence (Kaiser, 1961) that meteor showers lose their identity and merge into the sporadic background when large numbers of very faint meteors are being detected. The Pisces Australid, Southern

ι-Aquarid, Capricornid and Cetid showers have disappeared in this way from the curves in Figure 5, even though they are known to be active at that date. At least two of them (Pisces Australids and Cetids) were present in similar records obtained at lower sensitivity, and hence lower rate, on the same date in 1956.

The above situation is well illustrated by the records obtained in early December, 1962, a time of the year when several well known southern showers are active (Ellyett, Keay, Roth and Bennett, 1961). The principal two are the Velids and the Puppids, which, together with the Librids and the Orionids, are marked on the partial rate curves obtained during December 4 (Figure 6) and December 5 (Figure 7). Of the 72 times when a peak should have been present fewer than five coincidences were obtained. Even when allowance is made for inaccuracies in the quoted radiant positions there are no clear sequences of peaks (such as that for the δ-Aquarids in Figure 5) which reveal shower activity. Furthermore, when the corresponding partial rate curves for each of the two days are intercompared there is very little continuity between them, despite the fact that each of the showers mentioned above lasts for several days. It is also noticeable that some of the sharper and more prominent peaks one day are replaced by dips in the curve on the next day.

Only the gross characteristics of the partial rate curves relate to one another or persist from day to day. They are the gradual rise in rate from midnight to approximately 0600 hours, the hollow centred near 0900 hours and the broad hump at around 1200-1300 hours followed by the decline in rate towards the evening. Such a finding is consistent with the pattern which emerged from a year-long survey of meteor activity in 1960-61: the broad helion and anti-helion peaks or groupings then also over-shadowed almost all shower activity (Ellyett and Keay, 1963). This is clearly shown by combining the daily partial rate curves over a period of one week, as has been done in Figure 8. Although each successive daily curve was shifted four minutes to minimise the spreading of peaks due to the shift in solar longitude, there is little sign of peaks due to discrete meteor showers. (The points for each curve were smoothed in sliding groups of three in order to reduce statistical fluctuations and show genuine peaks of activity more clearly.)

In all of the curves shown in Figure 8 the two diurnal peaks are evident and there is a third peak in at least two of the records obtained from the antenna directed due east. While the two principal peaks are not as sharp as those in Figure 5, indicating less concentrated activity, the mean radiant positions have been calculated by the method outlined earlier.

The co-ordinates obtained for the mean radiant of the early morning activity are

Right ascension $138.4^\circ \pm 3.4^\circ$

$(\lambda_\odot = 255^\circ)$

Declination $-44.2^\circ \pm 8.7^\circ$

which definitely associates it with the well-known Velid shower, as illustrated in Figure 9 (a). This radiant is well removed from the vicinity of the ecliptic. It is situated at an ecliptic latitude of -56° which suggests that there may exist, for this part of the year at least, a southern counterpart to the high inclination meteoric activity observed from the northern hemisphere (Hawkins, 1963).

The midday peak of activity yields the co-ordinates

Right ascension $238.8^\circ \pm 3.5^\circ$

$(\lambda_\odot = 255^\circ)$

Declination $-26.4^\circ \pm 12.4^\circ$

for its mean radiant. This activity therefore originates from the vicinity of the ecliptic, as revealed by Figure 9 (b), and is very close to the Librid radiants found in earlier work (Ellyett, Keay, Roth and Bennett, 1961).

At the high rates of meteor detection obtained with the present apparatus (total rates exceeding 1000 per hour were quite usual during December 1962) it was found that the small peaks in the daily partial rate curves rarely coincided from day to day, yet the broad peaks remained present. In view of this fact it would appear that each of the two mean radiant positions obtained represents a centre of rapidly and constantly shifting activity. This type of behaviour has previously been observed in the case of the Velid shower by Weiss (1960), who reports that its radiant is very ill-defined. In a series of observations from 1953 to 1960 (at lower echo rates than the present work) recently collated by Ellyett and Roth (1964), several centres of activity were found. Two of the strongest centres are plotted in Figure 9 (a). The conservation exhibited by most of the small peaks in the daily partial rate curves (which are unsmoothed) is, however, quite high, which tends to suggest that the activity occurs in sporadic bursts of a few hours duration from numerous radiants scattered around the mean position.

5. ACKNOWLEDGMENTS:

This research was sponsored by the Office of Space Sciences, National Aeronautics and Space Administration, Grant NsG-219-62, with additional assistance from the Universities of New Zealand Research Grants Committee. The encouragement of Dr. C. D. Ellyett and assistance by E. C. McLauchlan and B. J. Fraser is appreciated.

6. REFERENCES

Aspinall, A., Clegg, J.A. and Hawkins, G.S., Phil. Mag., 42, 504, 1951.

Clegg, J.A., Phil. Mag., 34, 577, 1948 a.

Clegg, J.A., J. Brit. Astr. Assoc., 58, 271, 1948 b.

Ellyett, C. and Keay, C.S.L., Mon. Not. R. Astr. Soc., 125, 325, 1963.

Ellyett, C.D., Keay, C.S.L., Roth, K.W. and Bennett, R.G.T., Mon. Not. R. Astr. Soc., 123, 37, 1961.

Ellyett, C.D. and Roth, K.W., Aust. J. Phys., 8, 390, 1955.

Ellyett, C.D. and Roth, K.W. To be published.

Hawkins, G.S., Smithsonian Contrib. Astrophys., 7, 53, 1963.

Hoffmeister, C., "Meteorströme" (Weimar, 1948), 90.

Kaiser, T.R., Mon. Not. R. Astr. Soc., 123, 265, 1961.

Keay, C.S.L., Aust. J. Phys., 10, 471, 1957.

Keay, C.S.L. and Ellyett, C.D., J. Geophys. Res., 66, 2337, 1961.

Weiss, A.A., Mon. Not. R. Astr. Soc., 120, 387, 1960.

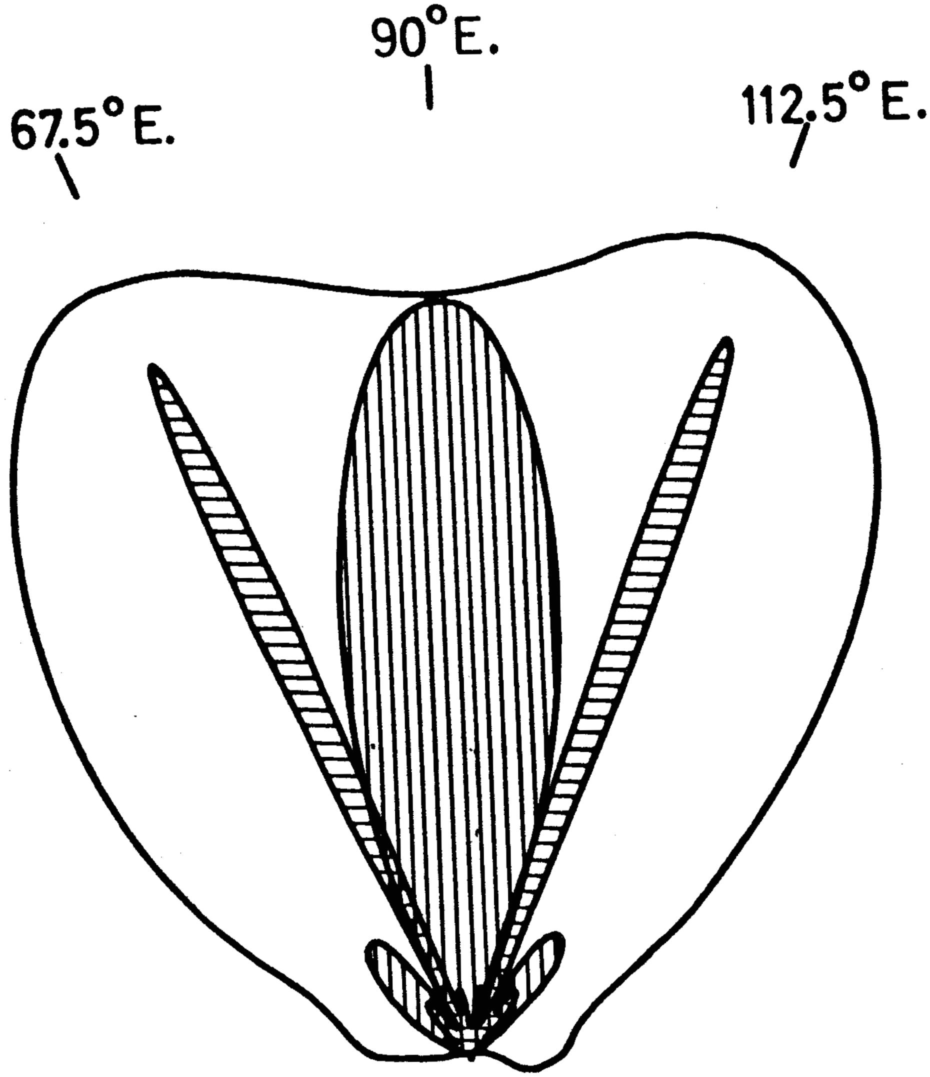

FIGURE 1. Plan view of antenna coverage. The outer curve represents the horizontal radiation pattern of the Fan-Beam transmitting antenna, while the horizontal patterns of the three narrow-beam antennas used for reception are shown shaded.

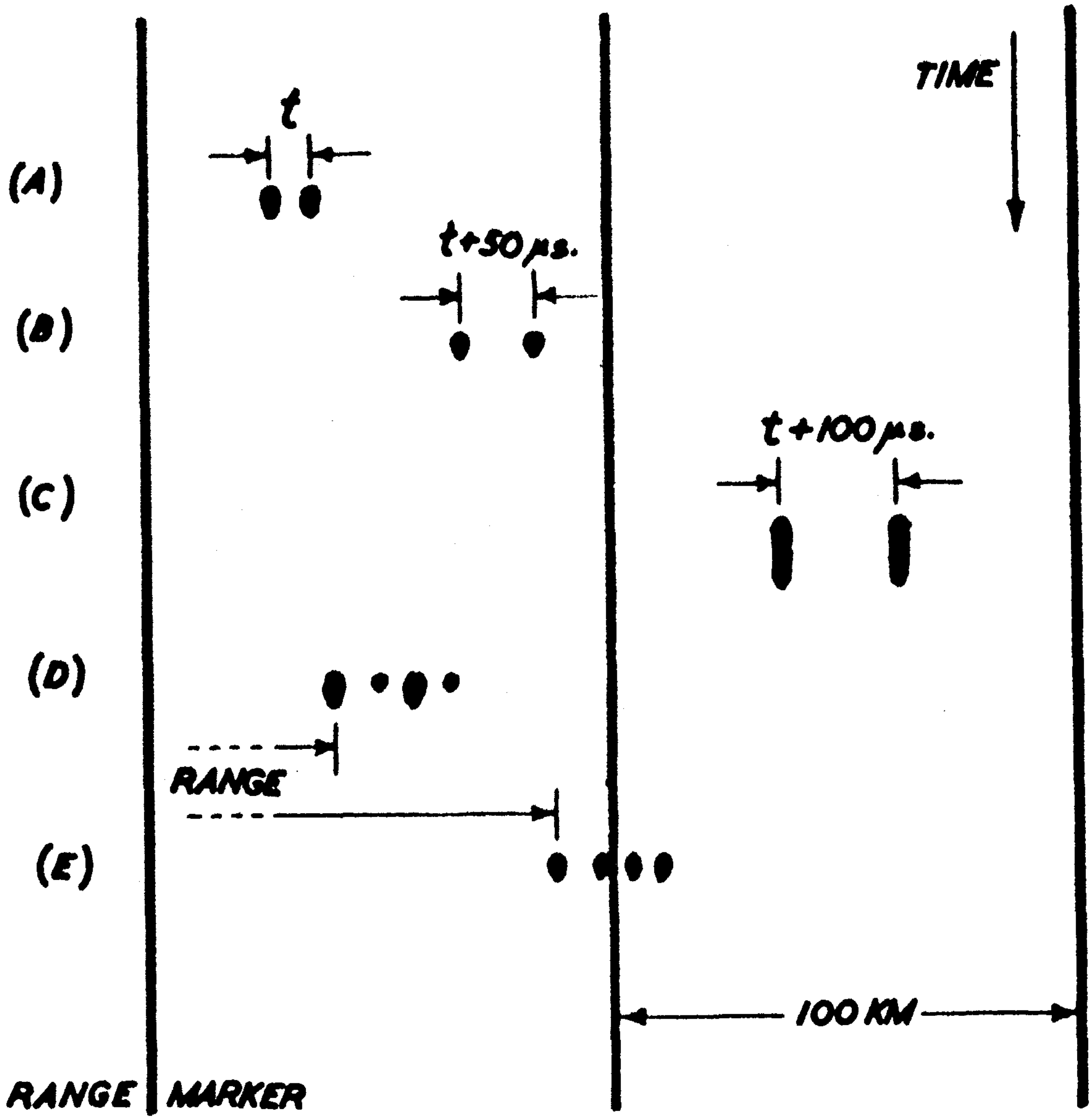

FIGURE 2. Triple-channel display of echoes. These schematic examples represent (A) an echo via Receiver 1, (B) an echo via Receiver 2, (C) a moderately long-duration echo via Receiver 3, (D) a strong echo received by Receiver 2 with weak returns via Receivers 1 and 3, (E) a relatively rare type of echo for which the signal amplitude appears the same from all three receivers.

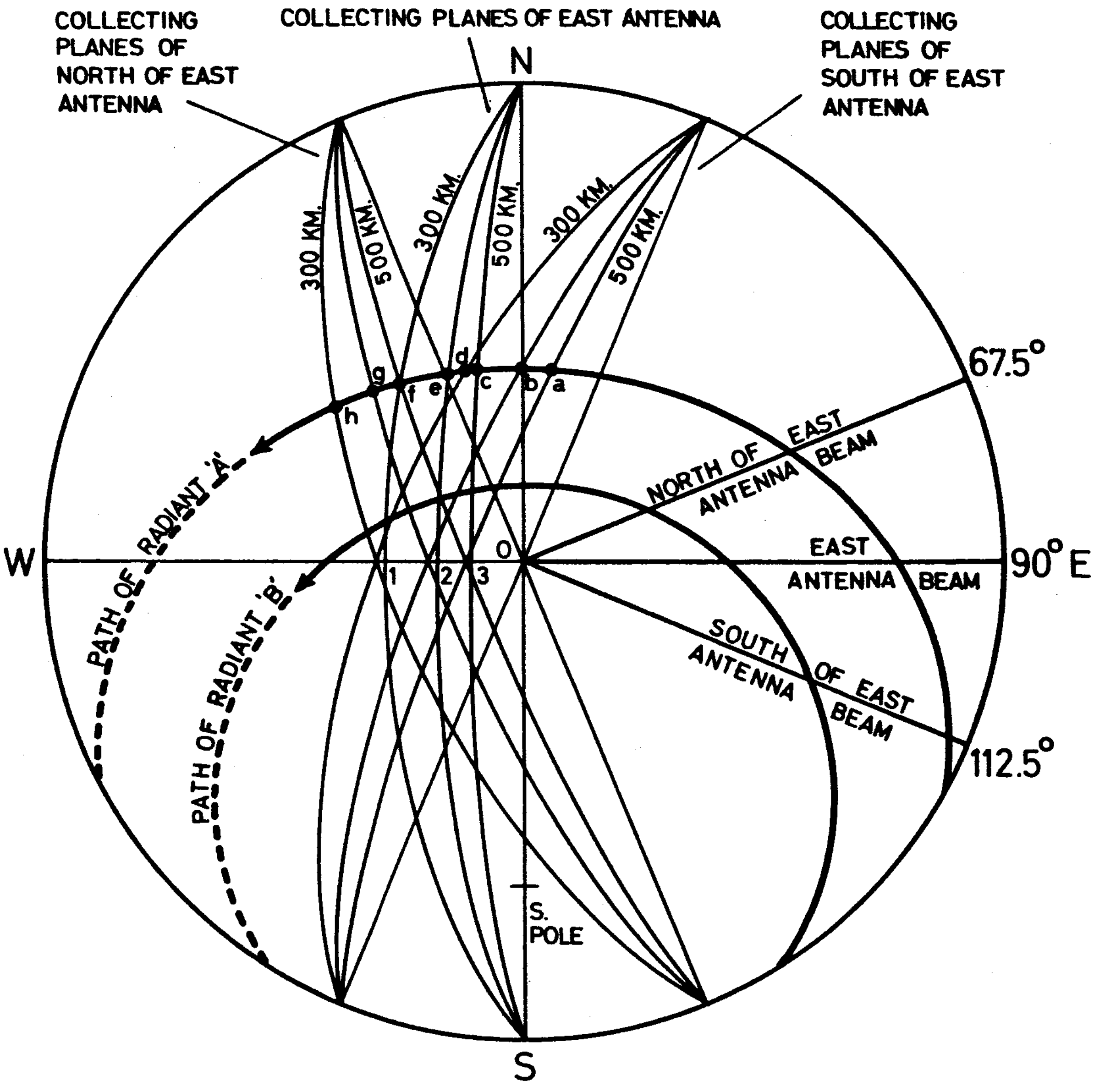

FIGURE 3. Horizontal projection of celestial hemisphere, showing the collecting planes for each of the three narrow beam antennas.

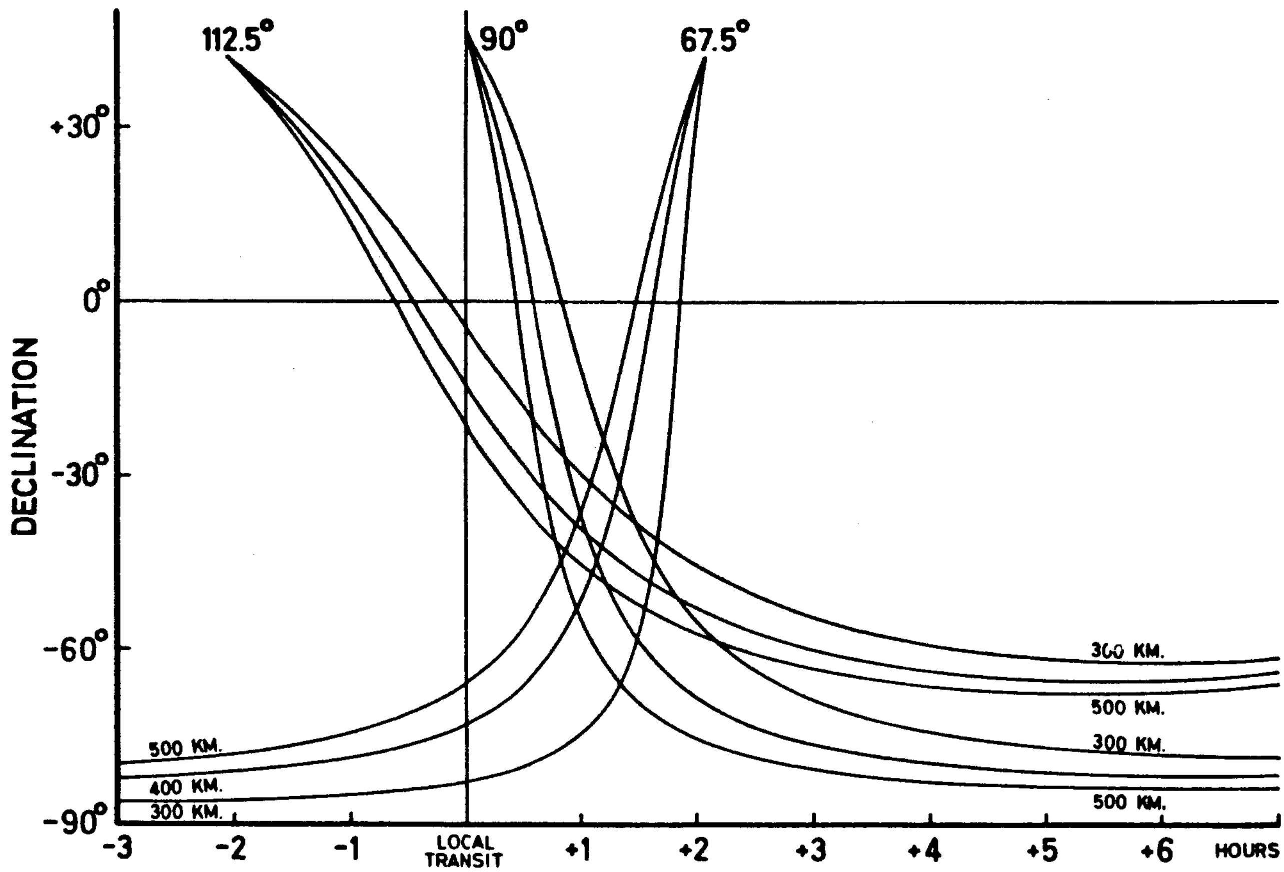

FIGURE 4. Times of reception of meteor echoes at various ranges in each of the three antennas, plotted as a function of radiant declination.

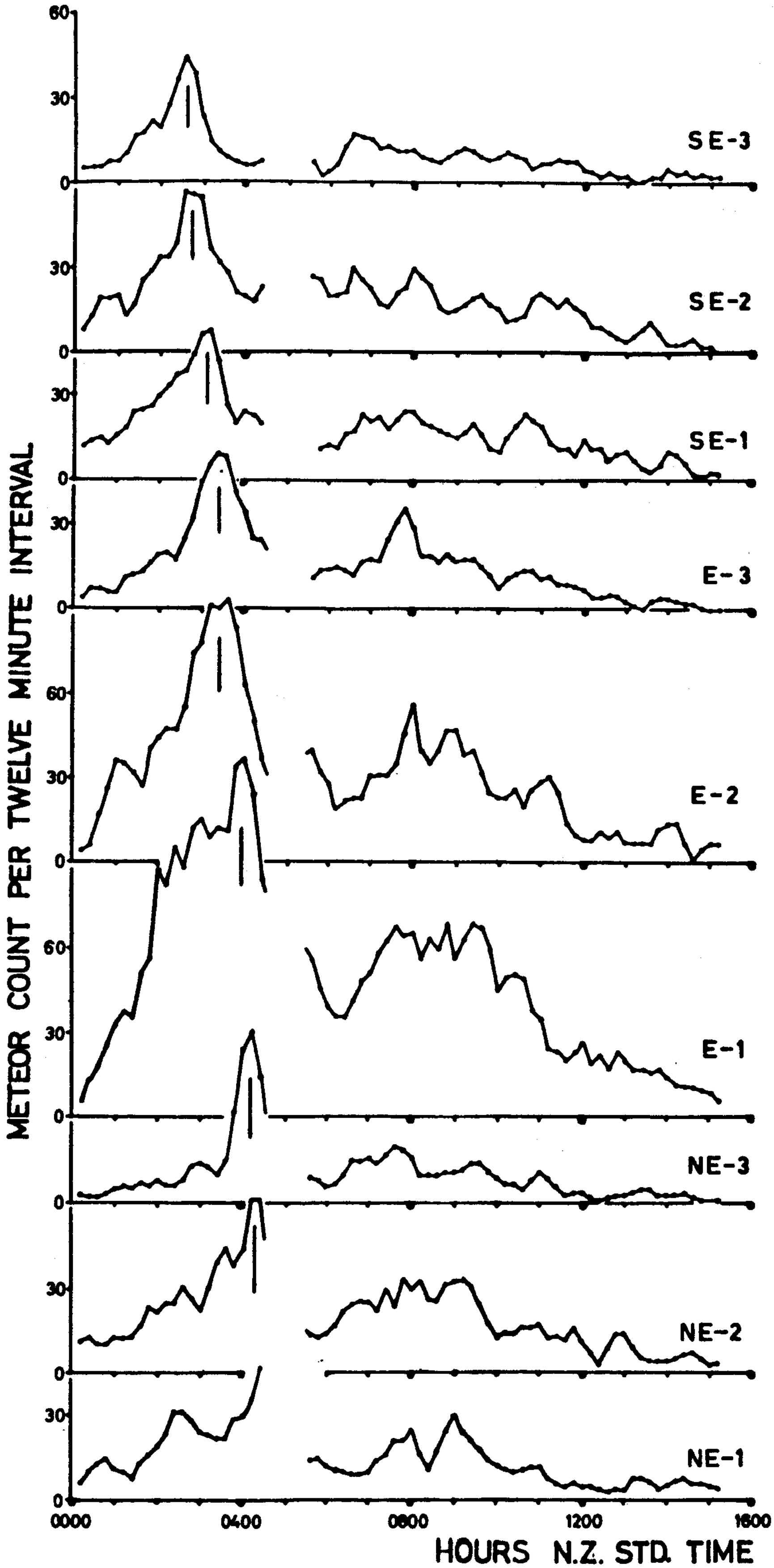

FIGURE 5. Partial rate curves for 1962, July 25. The Delta Aquarid shower is marked.

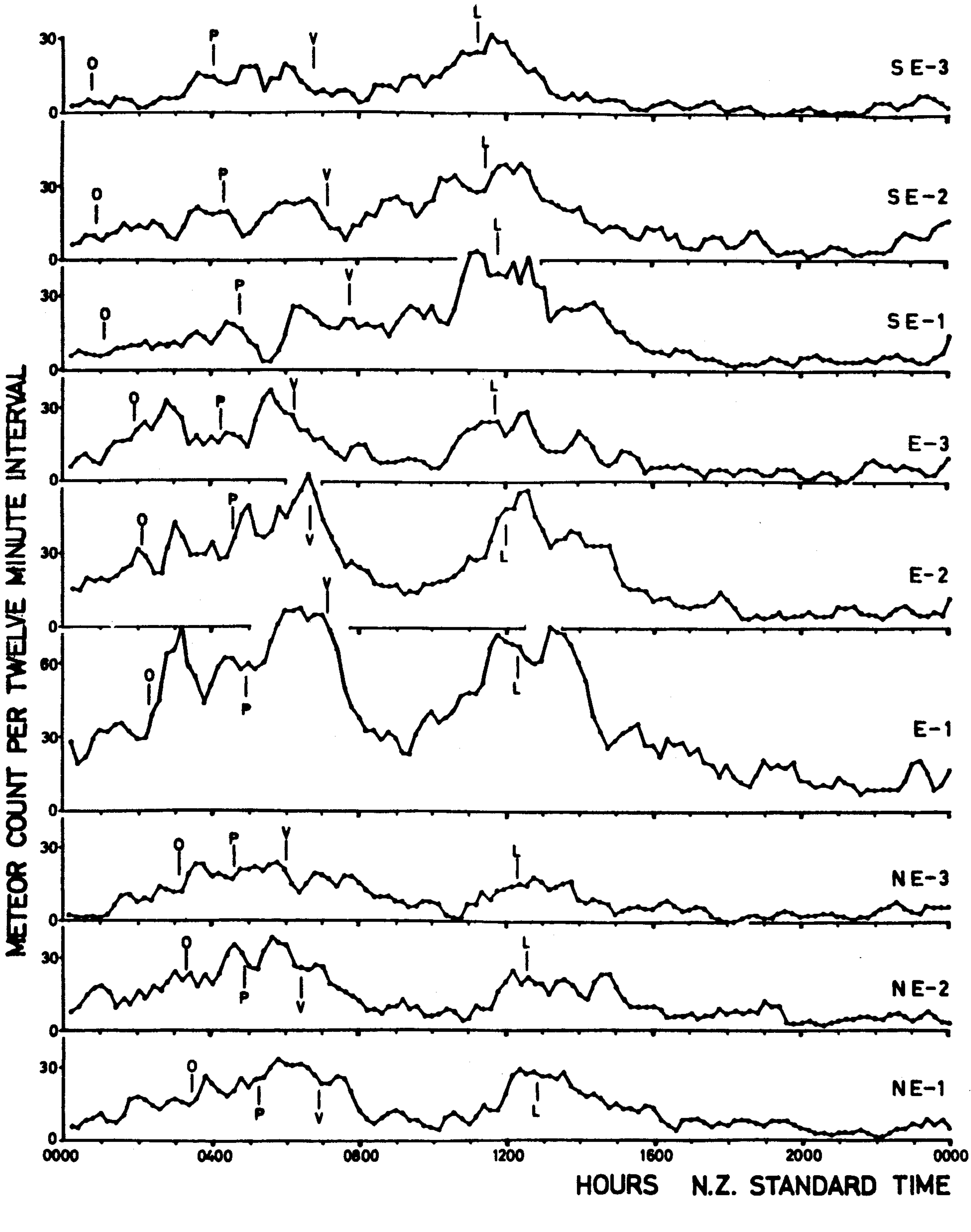

FIGURE 6. Partial rate curves for 1962, December 4.
"O" is where the Orionid shower was expected to appear
"P" " " " Puppid " " " " "
"V" " " " Velid " " " " "
"L" " " " Librid " " " " "

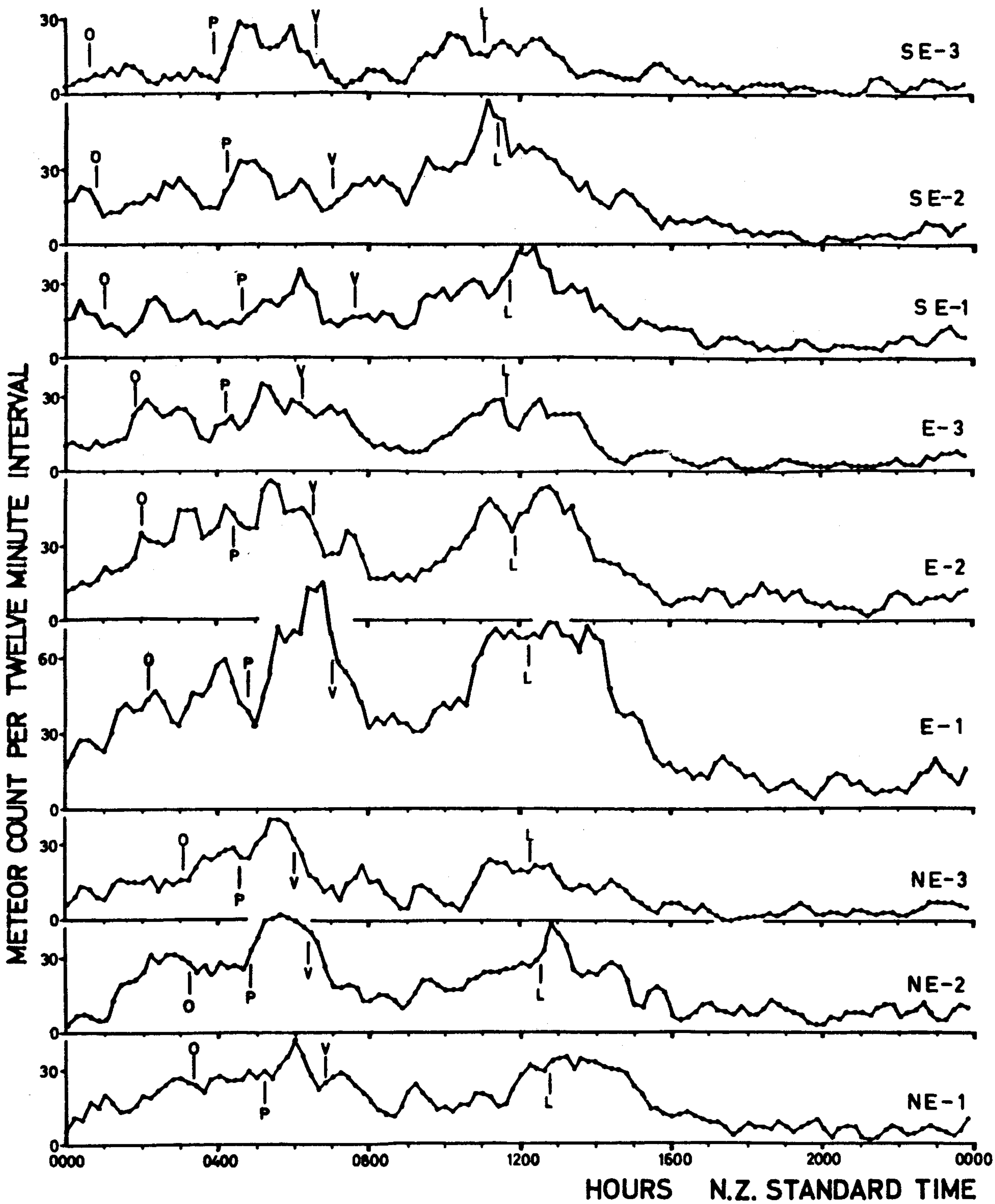

FIGURE 7. Partial rate curves for 1962, December 5.
"O" is where the Orionid shower was expected to appear
"P" " " " Puppid " " " " "
"V" " " " Velid " " " " "
"L" " " " Librid " " " " "

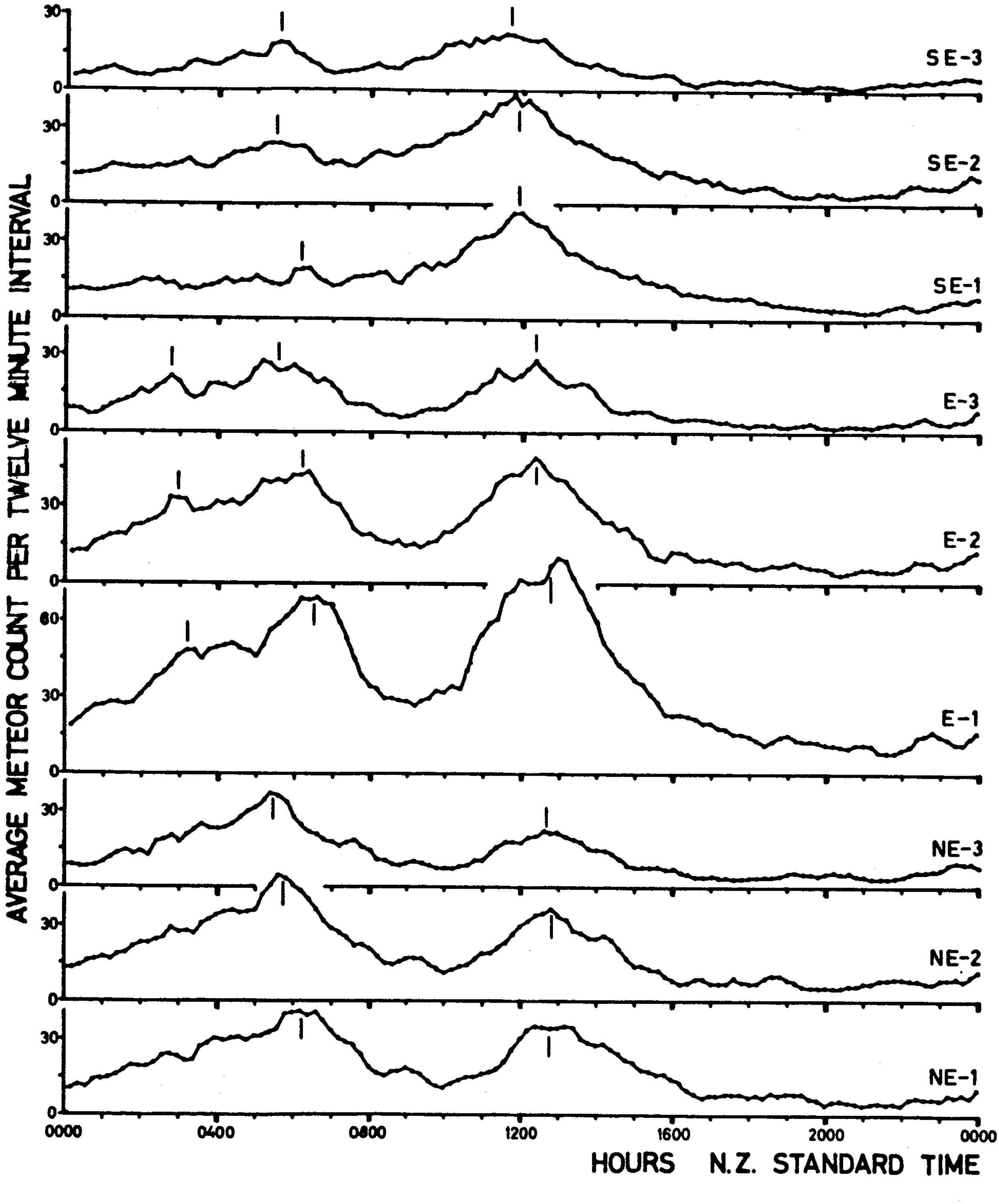

FIGURE 8. Mean partial rate curves for the whole week from December 4 - 10, 1962. The times adopted for the passage of each principal maximum of activity are marked.

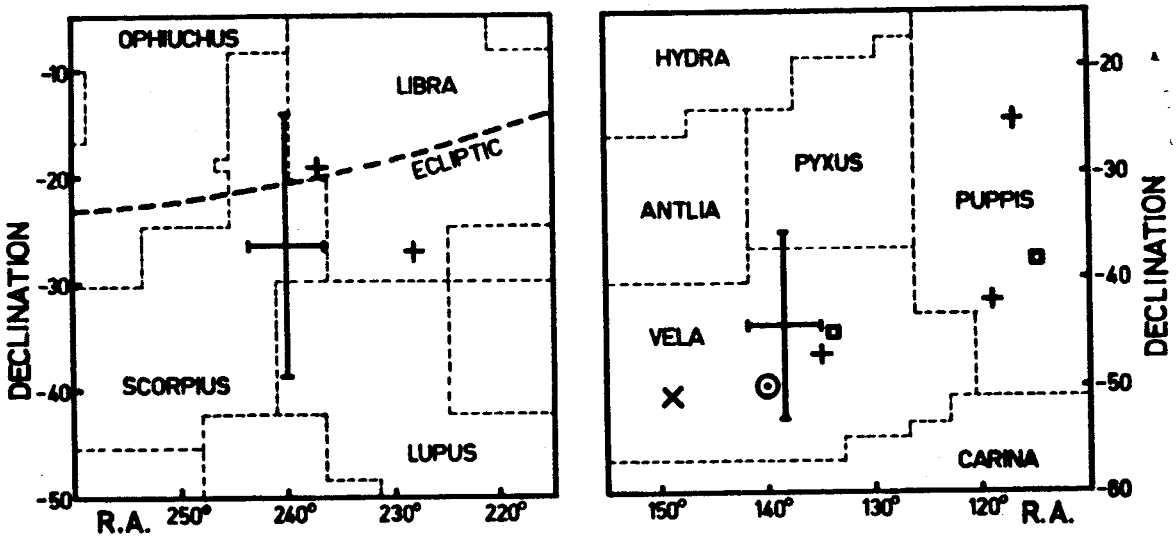

FIGURE 9. (a) A plot of the radiant position derived for the Librid-Scorpid activity together with the positions of Librid activity (crosses) found by Ellyett, Keay, Roth and Bennett (1961); (b) the radiant position derived for the Velid activity is shown together with the other Velid-Puppid radiants found by

X Hoffmeister (1948),
⊙ Weiss (1960),
\+ Ellyett, Keay, Roth and Bennett (1961),
◻ Ellyett and Roth (1964).